brilliant, friction is low ($f = 0,5$). At 850°C ($T/T_f = 0,68$) the process is identical to the one described earlier at 950°C ($T/T_f = 0,75$). First entrapment and b.u.e. formation are noted. Friction ($f = 1$) and wear are high. Rapid variations in friction force $\Delta f$ which correspond to the jumps caused by the disk lamellae are also noted.

At 550°C ($T/T_f = 0,56$), the track is reasonably smooth and the $\Delta f$ are low. At 650°C, $\Delta f$ increases significantly and track damage is noted.

## 4 Discussion and Conclusion

Visualization studies performed at 950°C under nitrogen with high temperature austenitic steels showed that:

1) build-up edges (b.u.e.) are formed on the pin and eliminated on the disk at regular intervals.

2) b.u.e.s are formed from debris which originated from disk wear.

3) each b.u.e. is formed gradually around a first debris entrapment which locates itself towards the front of the contact.

4) first entrapment gradually grows towards both front and rear of the contact.

5) front growth stems from debris entrained by the moving disk which enter the contact and are packed against the first entrapment. They fill the front of the contact and eventually form a prow ahead of the pin.

6) a thin zone, situated at the frontier of the b.u.e. and disk, flows towards the back of the b.u.e. thus filling the rear of the contact and insuring first entrapment back growth.

7) beyond a given length, the entire b.u.e. is detached from the pin and transferred to the moving disk.

Prow formation and the b.u.e.s have been described by many authors and observed for materials and conditions far different from those tested here. Both Cocks [6, 7] and Antler [8, 9] have shown that prow formation is due to flow through plastic deformation of the moving disk. Sasada, et al. [10] refer to orderly piled up streamline layers which result from plastic flow. Bill and Wisander [11] Landheer and Zaat [12] show trails at contact exit of materials which have flowed plastically. Play and Godet [13] have shown that wear of high wear materials is controlled by debris drawn from the front to the back of the contact. Flow conditions or transport at contact are therefore not specific to high temperature friction processes. The notion of transport or flow which was clearly seen at high temperature can therefore be generalized to a large number of apparently unrelated conditions. Independently of the flow conditions, all authors have related prow or edge formation to the relative hardness of the pin and disk. More specifically Predmore, et al. [14] have shown that the b.u.e. on the pin of a pin and disk machine can only occur if the ratio of the pin to disk hardness is equal to or greater than one. This also agrees with the results presented here for which the hardness ratio is equal to one.

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## DISCUSSION

### H. E. Sliney[1]

The authors give a very interesting description of the behavior of wear debris in the vicinity of a sliding contact. They show that wear debris accumulates at the contact inlet to form so-called built-up-edges (b.u.e.) that feed "third body" material into the contact. It has been shown (reference [15]) that solid lubricant particles also form (b.u.e.) that act as reservoirs which feed lubricant to the contact. These observations imply that the factors which encourage the transport of solid particles through the contact are detrimental if the particles are non-lubricants and beneficial when the particles are lubricants.

What, then, are the factors that influence this transport? One important factor would appear to be the inlet geometry of the contact. A converging geometry is probably needed to draw solid particles into the contact. It should be noted that the pin specimens used in this study had a very generous chamfer around the perimeter of the contact thus creating a converging inlet. It would be interesting to determine the effect of chamfer angle on the accumulation and transport of particles through the contact.

Another important factor in the transport of solid particles through the contact in the presence or absence of a liquid lubricant. It is known that solid particles readily enter the converging inlet to dry Hertzion contacts. Solid lubricant particles undergo extreme plastic shear into very thin films. Brittle particles, on the other hand, are pulverized into very fine powder during their entry and transport through the contact.

However, these observations apply to dry contacts. The situation with an oil present may be very different. It is possible that with an oil film between the particles and the moving surface, slip will occur which will prevent the particles from being worked into the contact. The particles would then merely collect at the inlet or be swept around the contact. This effect could be beneficial in excluding abrasive particles from a contact, but could also negate any hoped for beneficial effect of solid lubricants in oil dispersions. However, the relative shear strength of the particles compared to the oil film is likely to be important and low shear strength solid lubricants are much more likely to be drawn into an oil lubricated contact than are hard, abrasive particles. This hypothesis involves the following assumptions: (1) the solid particles are larger than the oil film thickness in the contact; (2) the contact is in pure sliding; and (3) the surfaces of the contact are smooth. These assumptions are necessary because: (1) particles smaller than the oil film thickness should readily enter the contact;

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(2) any rolling component of motion is likely to trap particles within the contact regardless of their shear properties; and (3) surface irregularities can mechanically entrain particles into the contact.

A basic study such as the authors have described in this paper is very welcome in stimulating scientific thought and debate. I am sure the paper has implications well beyond those that are suggested in this discussion.

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## Authors' Closure

The authors wish to thank Dr H. E. Sliney for his comments and for his interest shown in this paper. We do agree with him that this work is centered around the notion of third body transport and third body load carrying capacity, even though in this case specific geometric effects are introduced through built-up edge production. Thus, the inlet geometry becomes one of the governing parameters of the process as it controls the manner in which the debris are either trapped and recirculated in or eliminated from the contact. This effect was however not studied here for practical reasons, it was however analyzed with two other materials [16]:

-a plastic pin rubs against a steel disk. A 30° entry chamfer decreases wear by a factor of three.

-a chalk pin rubs against a frosted glass disk [17]. Tests have shown that a chip is formed ahead of a square pin running on a preformed chalk trace, the original trace is thus destroyed. No such chip is observed with a chamfer, and particles from the original trace tend to recirculate in the contact. Evently, due to wear, the chamfer is eliminated and the chip reappears.

Inlet geometry effects are studied in detail in lubrication [18]. Unfortunately a similar analysis cannot be performed for the other materials tested as the constitutive laws of the transferred films are unknown today. However, flow and stretch effects can be taken into account qualitatively. Further, progress can be made if one considers a carrier fluid for which the "no slip at the wall" boundary condition applies which entrains particles with known mechanical properties.

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